Statistics of the Filtered Scalar Dissipation Field in Turbulent Reacting Flows

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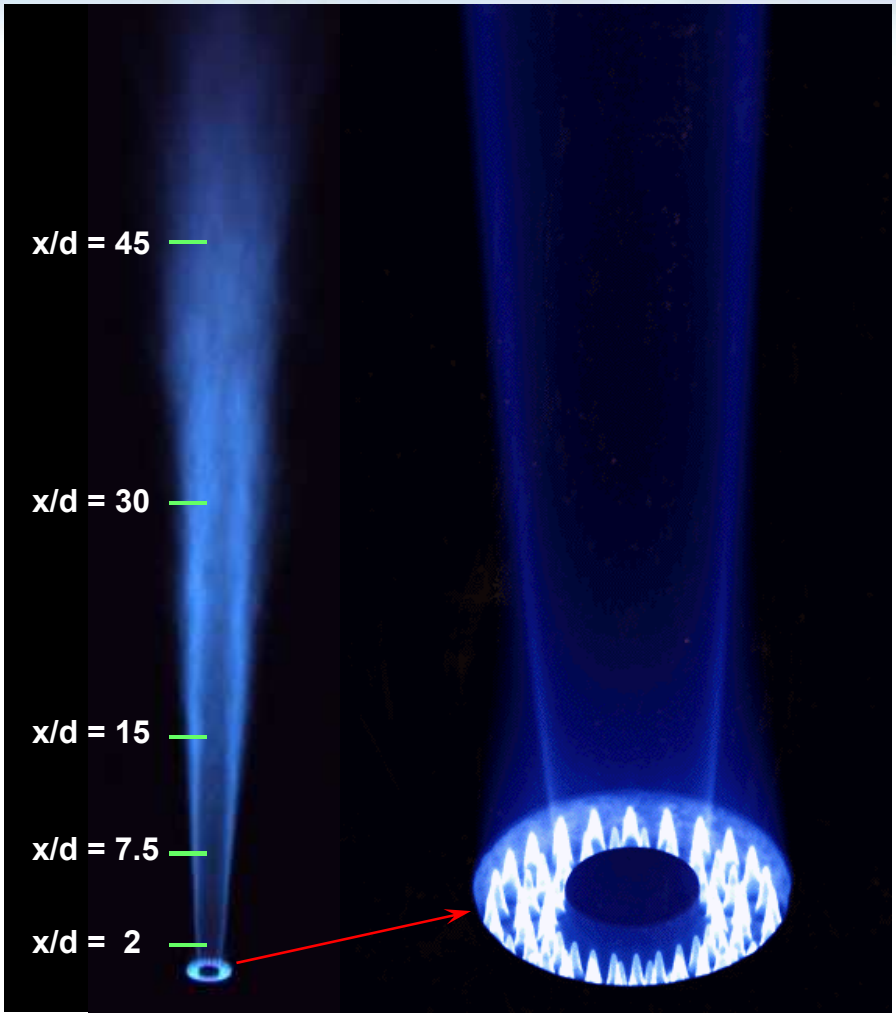
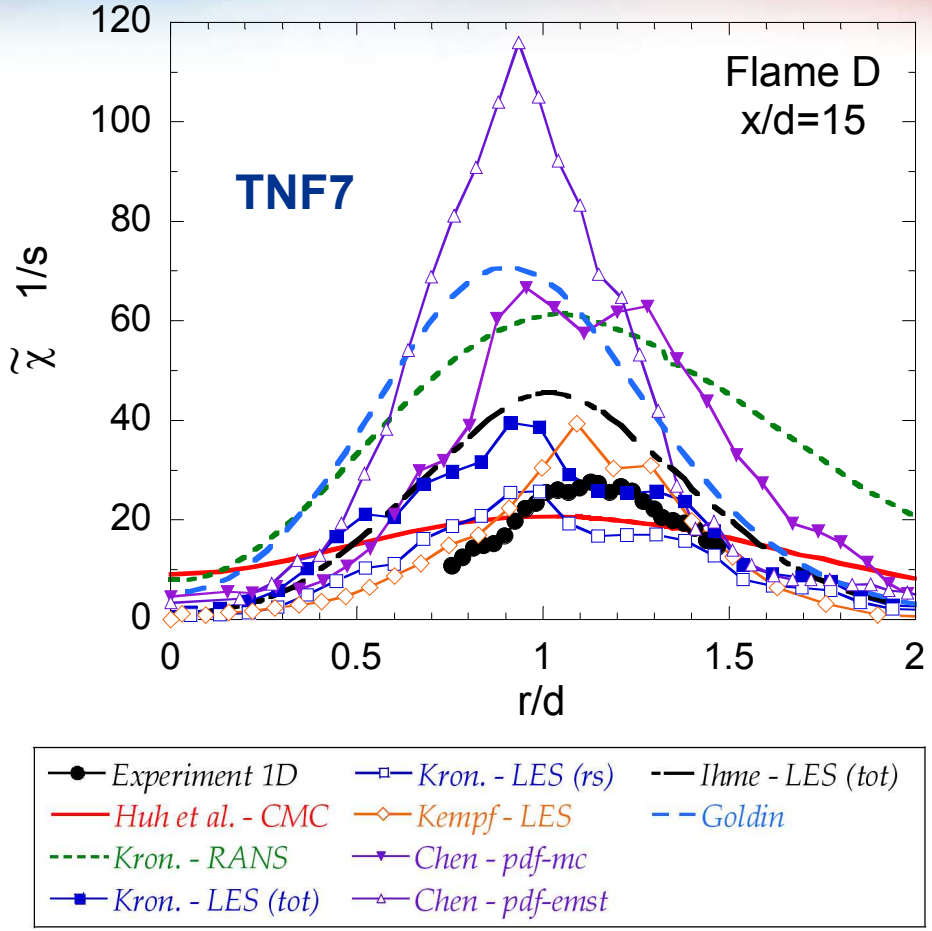
Problem

- **Scalar dissipation is of great interest for modeling turbulent non-premixed combustion**
  - **Definition:** $\chi = D\nabla\xi \cdot \nabla\xi$ **where** ξ **is a conserved scalar and** D **the scalar diffusivity**
  - **Physically interpreted as a molecular mixing rate (or equivalently rate at which fluctuations in** ξ **are destroyed)**
  - **Mathematically represents losses associated with scalar energy**

- **<u>Objective</u>: Develop relationship between statistics of the local and spatially filtered scalar dissipation rate**
  - **Has direct implications for development of subgrid-scale models for the Large Eddy Simulation technique**
  - **Will also help establish a better fundamental understanding of turbulence-chemistry interactions in nonpremixed flames**

“Simple” Flames Still Challenging: Variation in Modeled Scalar Dissipation … Why?





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Approach

- **Obtain relationship between $P(\chi)$ and $P(\tilde{\chi})$ through the relation**

$$P(\chi) = \int P(\chi \mid \tilde{\chi})\, P(\tilde{\chi})\, d\tilde{\chi}$$

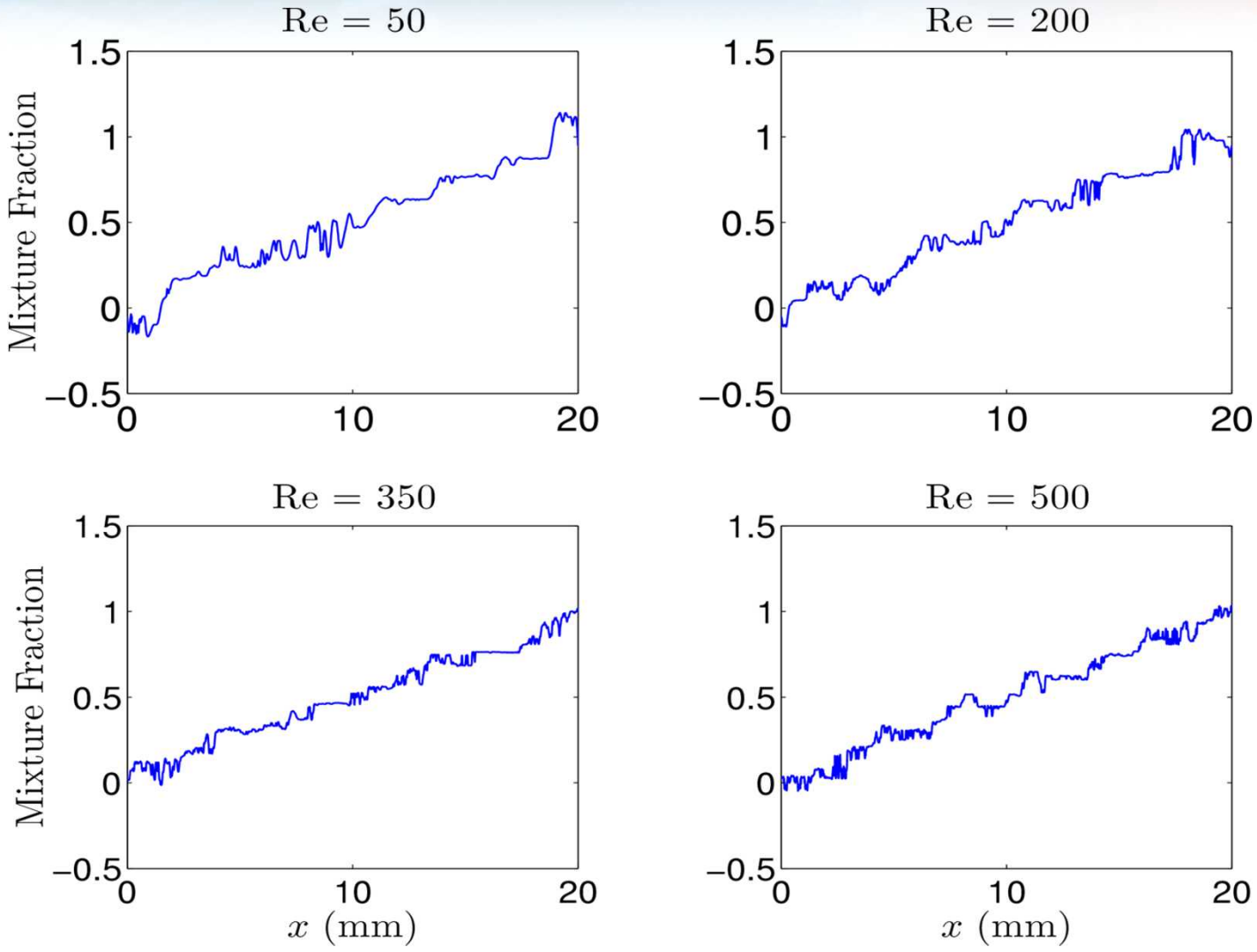
  - χ **is the instantaneous local value of scalar dissipation**
  - $\tilde{\chi}$ **is the filtered value of scalar dissipation**

Statistics of Scalar Dissipation are Obtained using the Linear Eddy Model (LEM)

- **LEM simulates the evolution of a scalar field as a function of molecular diffusion and turbulent advection in *one dimension***
  - **Molecular diffusion resolved explicitly**
  - **Turbulent advection modeled with "*triplet maps*"**
  - **Complete resolution of all length/time scales**
- **Uniform scalar gradient is specified as initial condition**
- **Jump-periodic boundary conditions used to obtain non-trivial statistically steady state**
- **Filtering is performed using a top hat filter:**

$$\tilde{\chi} = \int G(x - x')\,\chi(x')\,dx'$$

Representative Snapshots of Mixture Fraction Field



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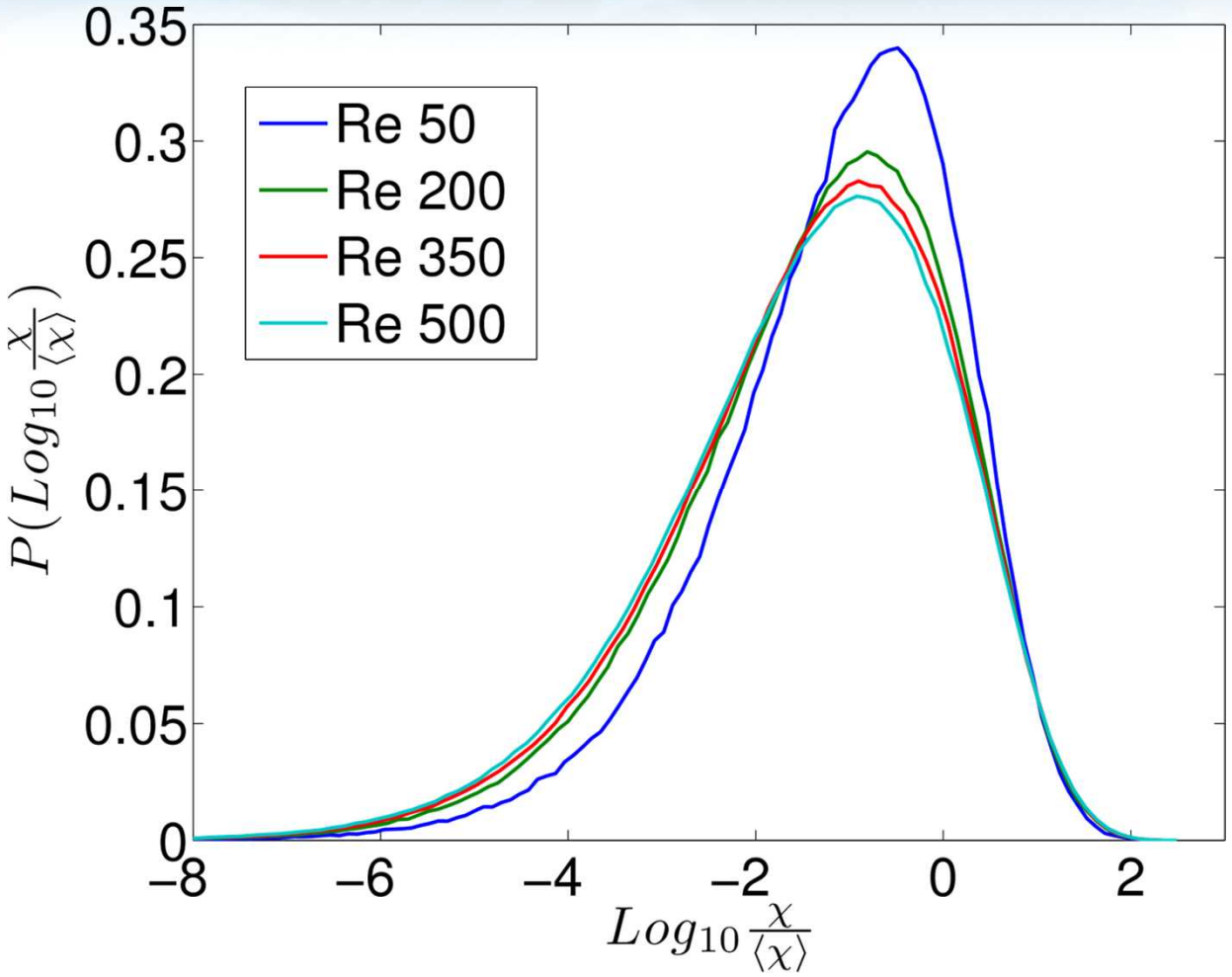
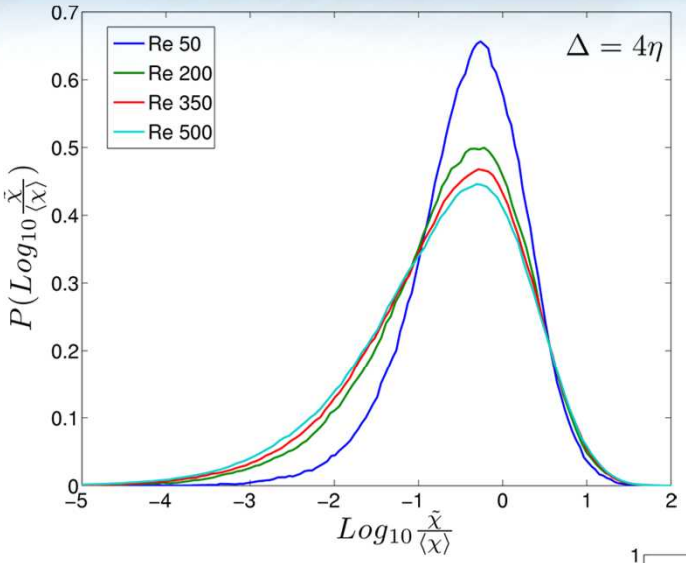
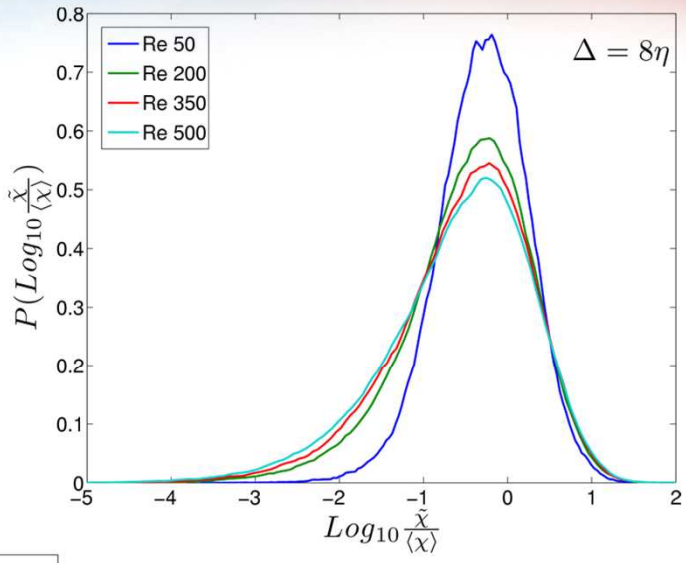
PDF of Unfiltered Scalar Dissipation Rate $P(\chi)$

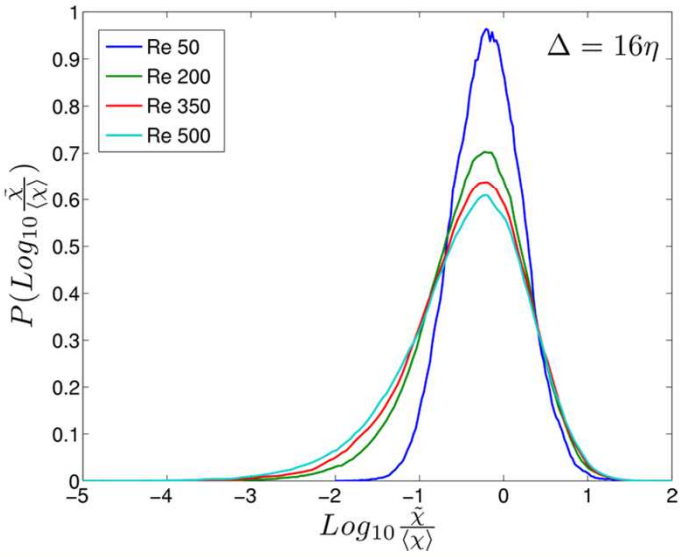


- **Computed distributions exhibit a high degree of lognormality, even at low Re**
- **PDF shows dependence on Re (peak decreases and variance increases with increasing Re)**
- **Results are in agreement with the past experimental and numerical studies**

PDF of Filtered Scalar Dissipation Rate $P(\tilde{\chi})$







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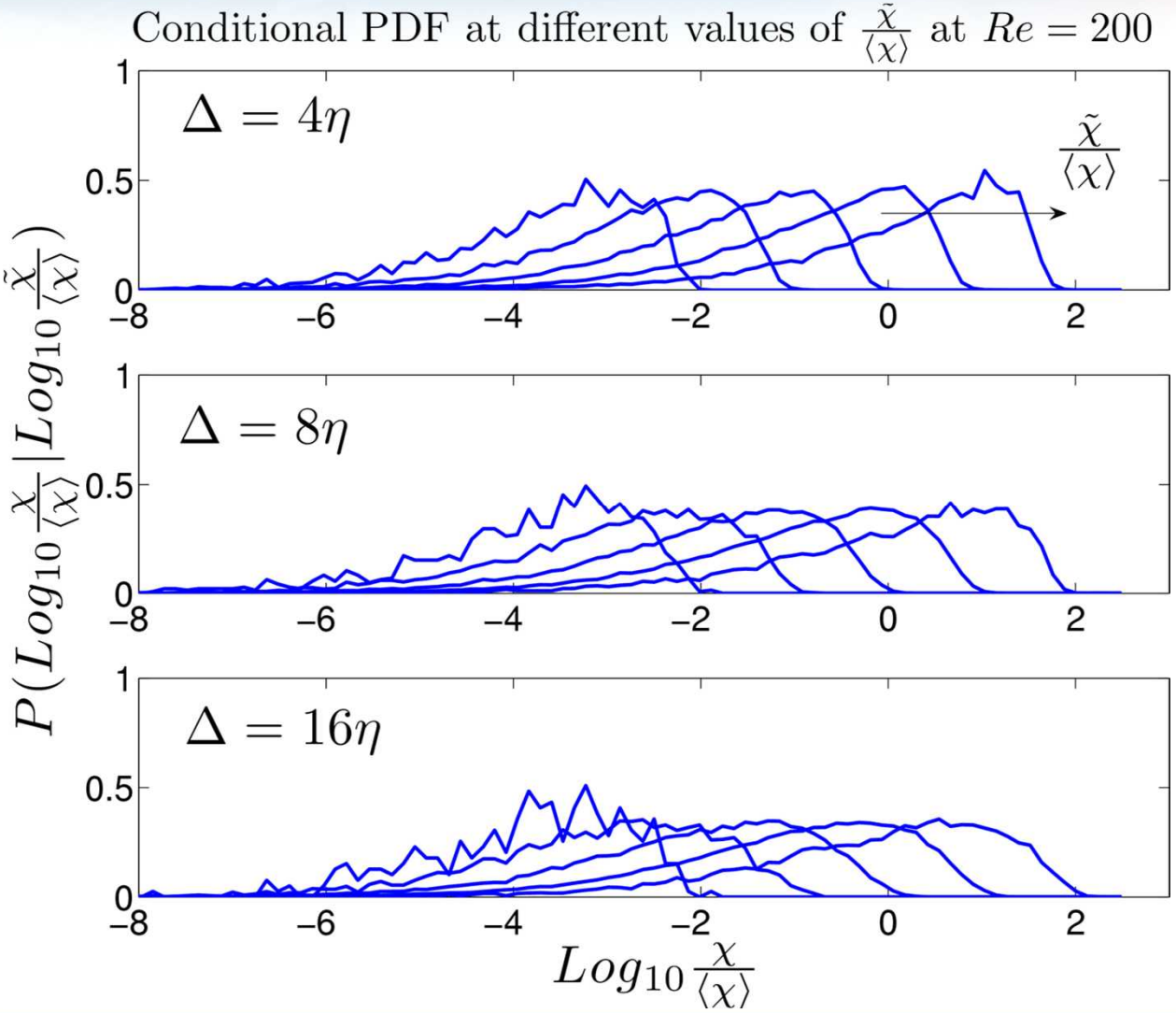
PDF of Filtered Scalar Dissipation Rate $P(\tilde{\chi})$

- $P(\tilde{\chi})$ **is also lognormal**
- **Gurvich and Yaglom hypothesized lognormal distribution for** $P(\tilde{\chi})$ **based on self-similarity of the energy cascade**
- **Kerstein and Ashurst's numerical study confirmed the lognormality of the filtered dissipation rate**
- **Current results are in good agreement with the past studies**
- $P(\tilde{\chi})$ **shows dependence on the filter size** Δ

Conditional PDF at Re = 200



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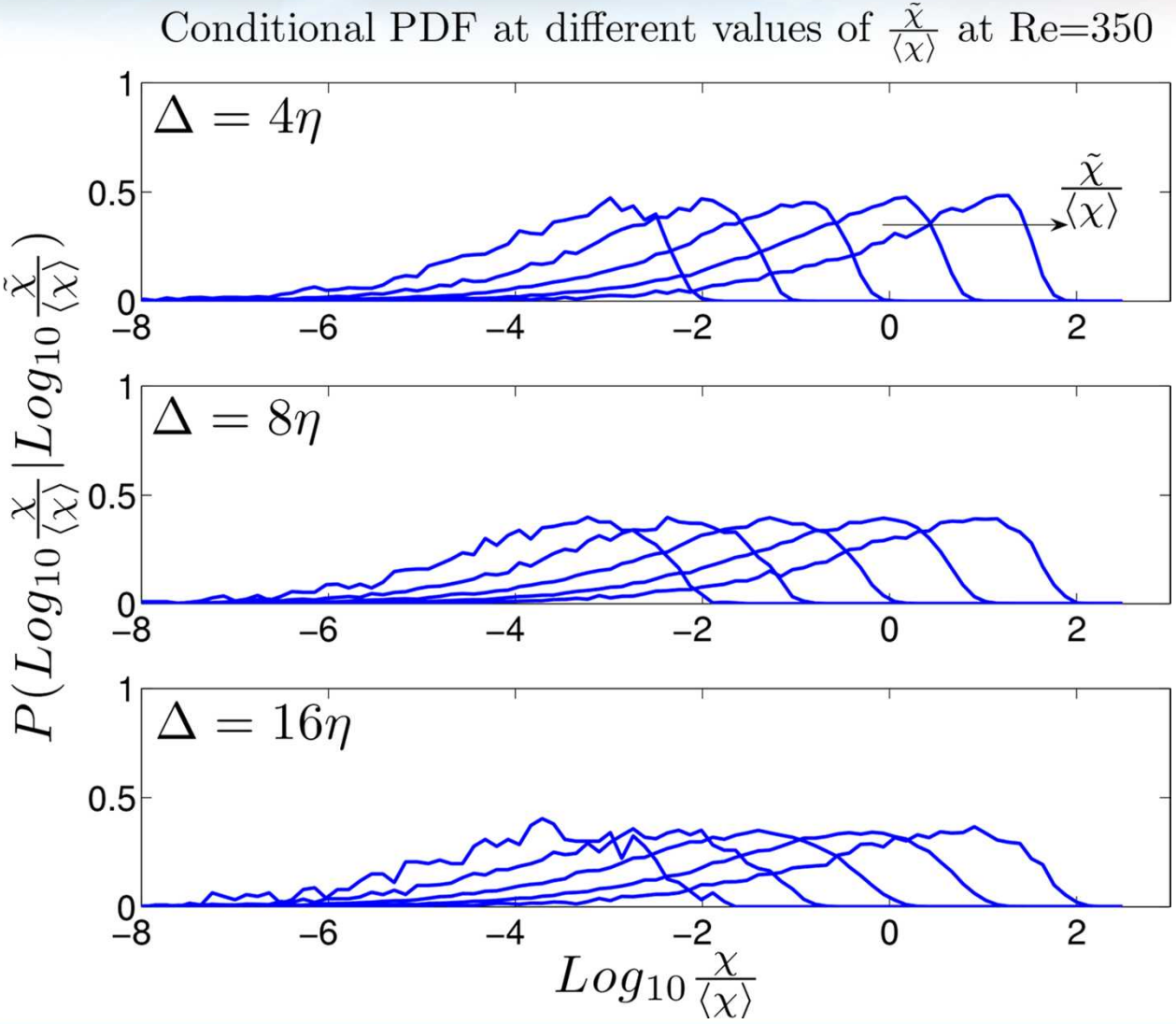
Conditional PDF at Re = 350



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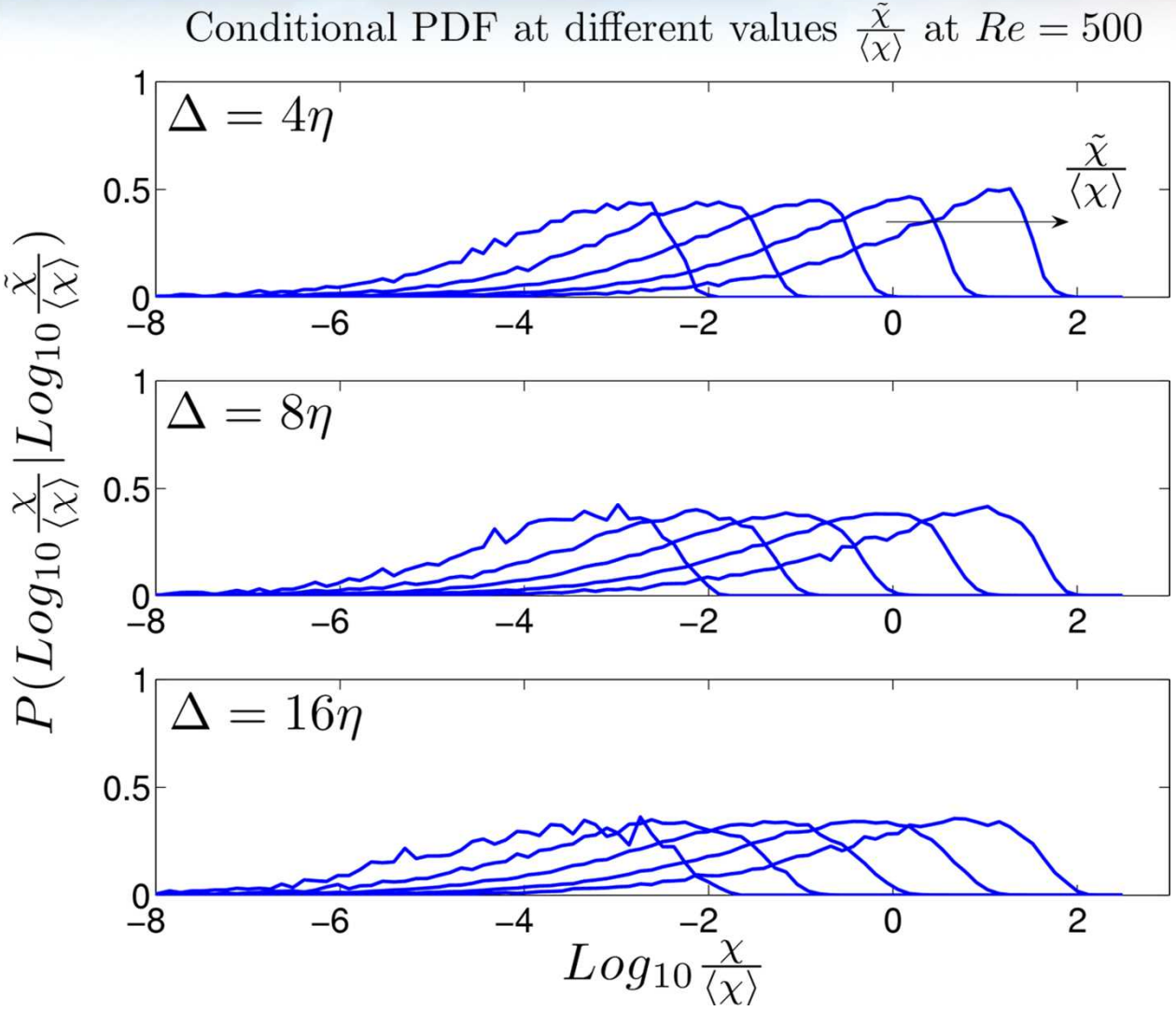
Conditional PDF at Re = 500



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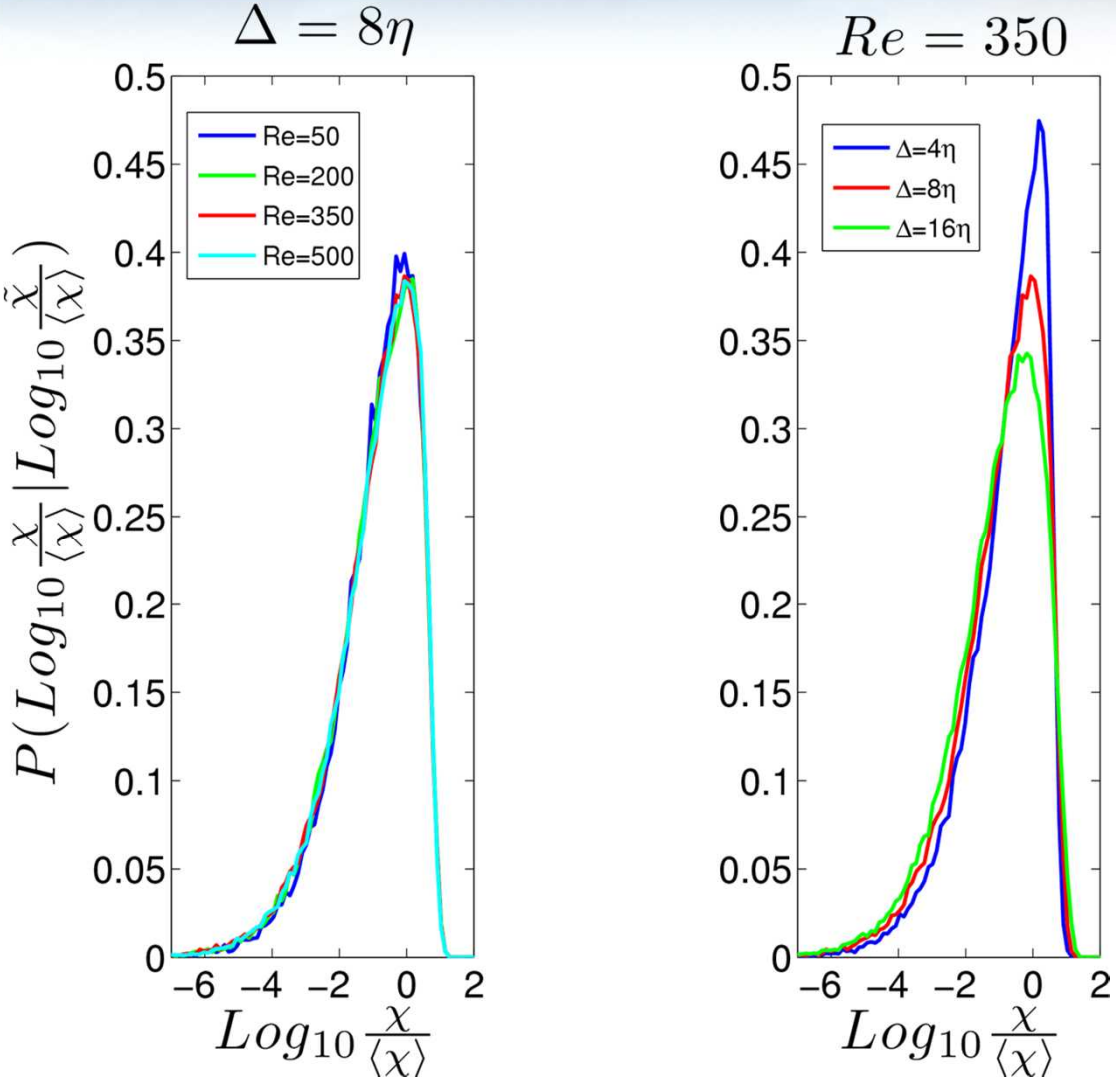
Sensitivity of Conditional PDF



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Conditional PDF: Summary of Trends

- **Conditional distribution of scalar dissipation is lognormal**
- **Depends only the relative filter size Δ/η**
- **Independent of integral scale Reynolds number Re_L**
- **Implications for LES:**
  - **A lognormal model for subgrid scalar dissipation based on $P(\chi \mid \tilde{\chi})$**
  - **Parameters of the lognormal model depend only on the filtered quantities and filter size, as long as the filter size is in the inertial range and bigger than the Kolmogorov scale**
  - **Independent of large scale effects from the boundary conditions**
  - **Parameters of the lognormal distribution can be estimated accurately from DNS of canonical flows**

Conclusions and Future Work

- **Instantaneous scalar dissipation exhibits lognormal behavior**
- **Filtered scalar dissipation also exhibits lognormal behavior**
  - **Dependence on filter size and Re_L**
  - **Consistent with Kolmogorov theory**
- **Conditional PDF or subgrid distribution of the scalar dissipation is also *lognormal !***
  - **Strong relevance to LES modeling**
  - **Reliable estimates of the parameters of the lognormal model can be obtained from canonical flows without considering large scale effects**
- **Future work:**
  - **Study statistical dependence of mixture fraction and scalar dissipation**
  - **Extend the analysis for the effect of Schmidt number**
  - **Extension to reacting flows**